A Cognition-Based Interactive Game Platform for Learning Chinese Characters

Chao-Lin Liu† Chia-Ying Lee‡ Jie-Li Tsai§ Chia-Ling Lee↑

†↑Department of Computer Science, National Chengchi University, Taiwan

‡Institute of Linguistics, Academia Sinica, Taiwan

§Department of Psychology, National Chengchi University, Taiwan

†‡§Research Center for Mind, Brain, and Learning, National Chengchi University, Taiwan

{†chaolin, §jltsai, ↑96703032}@nccu.edu.tw, ‡chiaying@gate.sinica.edu.tw

ABSTRACT

Evidence observed in classrooms and findings reported in neurolinguistic research have suggested that awareness of the correspondence between graphemes and phonemes in Chinese is instrumental for effective learning of Chinese characters. We collected and analyzed errors in written Chinese characters, and found that phonologically related factors also participated in a large proportion of the reported errors. To verify and evaluate the influence of the phonetic awareness on learning Chinese, we built interactive games for computer assisted learning of Chinese characters. A software tool was implemented to recommend Chinese characters that are phonetically or visually similar, and we applied this tool to assist the task of selecting useful characters in designing the games. We discuss the related findings of ours and the designs of the games, but results of the final evaluation will be available only in the oral presentation.

Categories and Subject Descriptors

K.3.1 [Computing Milieux]: Computer Uses in Education – Computer-assisted instruction (CAI); I.2.1 [Computing Methodologies]: Applications and Expert Systems – Games; J.4 [Computer Applications]: Social and Behavioral Sciences – Psychology; J.5 [Computer Applications]: Arts and Humanities – Linguistics

General Terms

Algorithms, Design, Human Factors

Keywords

Computer-Assisted Language Learning, Recognition of Chinese Characters, Errors in Chinese Texts, Chinese Text Processing, Serious Games

1. INTRODUCTION

Reading is a key step in language learning, and recognizing the words of a language is one of the most important prerequisites for reading. Chinese words are composed of individual characters. A Chinese word can contain a single character, two characters, or more characters, and Chinese texts do not use white spaces to separate individual words. Hence, we can say that recognizing individual Chinese characters is crucial for learning to read Chinese.

Recognizing words is a complex process that takes place in human brains. Employing appropriate apparatuses to monitor brain activities, psycholinguistic studies show strong correlations between the phonetic components within Chinese characters and the response time in naming tasks. Such results reveal possible ways to design course materials that help students learn Chinese characters in ways that are more effective than pure memorization [8].

In addition to the neurolinguistic evidence, we have analyzed more than 4000 reported errors in traditional and simplified Chinese texts [12, 13, 14]. The results indicate that phonetic similarities, which resulted from the sharing of phonetic components, played a significant role in the observed errors.

Based on the relevant evidence, we have designed interactive games for learning Chinese characters. The games utilize the cues for linking the connections between the sounds and the sublexical components of the Chinese characters to make the learning of Chinese characters more effective. We will show and discuss our games that adopt the Whac-A-Mole[1] philosophy. Within such games, we control the challenge levels for learners, where we manipulate such factors as the coverage and frequency of the character sets and the response speeds needed to whack the targets.

We discuss selected characteristics of the Chinese characters in Section 2, review relevant theories about language recognition in Section 3, report our analyses of reported errors in written Chinese texts in Section 4, and present the interactive games in Section 5, before making concluding remarks in Section 6.

2. CHINESE CHARACTERS AND WORDS

Chinese characters are single syllable. The pronunciation of a Chinese character involves at least a nucleus and a tone, where the nucleus contains a vowel that follows an optional consonant. In this paper, we show Chinese characters in their traditional forms, use the Hanyu pinyin method[2] to denote the sound of Chinese characters, and show the tone with a digit that follows the string of the phonetic symbols. In Mandarin Chinese, there are four tones. (Some researchers include the fifth tone.)

SAC'11, March 21-25, 2011, Taichung, Taiwan.

[1] http://en.wikipedia.org/wiki/Whac-A-Mole (last visited on 2 Nov. 2010)

[2] http://en.wikipedia.org/wiki/Pinyin (last visited on 2 Nov. 2010)

A Chinese word may consist of one or more characters, while most words contain two or three characters. It is not rare for multiple characters to carry the same sound in Chinese, but there are relatively much fewer words that share the same pronunciation. For instance, “搖”, “遙”, “瑤”, and “謠” are four characters that can be pronounced as /yao2/; and “遙遠” (yao2 yuan3) is a word containing two characters that means “far away” in English. In /yao2/, /y/ is a consonant, /ao/ is a vowel, and the number, 2, represents the second tone in Mandarin Chinese.

Traditionally, the formation of Chinese characters are classified into six categories, depending on how and why the components of a character were put together to form the character. Among these so-called *six writings* (in Chinese, 六書(liu4 shu1)), the ***phono-semantic compound*** category is by far the most common. For simplicity of our presentation, we refer to this category as the **PSC** category, henceforth.

A PSC character contains two components: one carries the information about the pronunciation, and the other semantics of the character. The characters “搖”, “遙”, “瑤”, and “謠” share a phonetic component “䍃”, and the remaining components, i.e., “扌”, “辶”, “𤣩”, and “訁”, respectively, carry semantic information about these characters. The shared phonetic component is the main reason for these four characters to have the same pronunciation.

Although it is a consensus that the PSC category is the most common category among the six writings, the estimates of the exact proportion of PSC characters in Chinese varied in the literature. The exact figures depend on which time period in history the researchers studied, and with what corpus that was used in the study. For modern Chinese, nearly 80% of Chinese characters belong to the PSC category [8, 20].

Therefore, effective strategies for learning the PSC characters will benefit learners of Chinese very much.

3. COGNITIVE EVIDENCE

In this section, we discuss some recent evidence that shows us why knowledge about phonetic elements constitutes a crucial factor in reading Chinese.

3.1 Grapheme-Phoneme Correspondence

For most people, particularly the native speakers, the learning of the writing system comes after the learning of the sounds of the target language. Children of only few months old typically do not read, but they can communicate with parents via the aural channel. Therefore, for such typical learners, learning written characters by learning the correspondence between the acoustic forms and the written forms of the characters will be a natural and effective style of learning [24].

In English, the correspondence between grapheme and phoneme is ***consistent*** if a string of characters is always pronounced in a specific way. The pronunciation for the string “ean” is not consistent. Although “ean” is pronounced in the same way in *b<u>ean</u>*, *cl<u>ean</u>*, *d<u>ean</u>*, and *l<u>ean</u>*, it is pronounced in another way in *oc<u>ean</u>*. The string “ch” is pronounced inconsistently in *<u>ch</u>ase*, *<u>ch</u>asm*, *ma<u>ch</u>ine*, *kit<u>ch</u>en*, *s<u>ch</u>ool*, and *stoma<u>ch</u>*. It is found that English is highly inconsistent in terms of the *grapheme-phoneme correspondences* (**GPCs**), while Finnish is highly consistent [24].

The Chinese phonetic components are not always consistent. In the previous section, we have seen a consistent phonetic component in “搖”, “遙”, “瑤”, and “謠”. In contrast, the shared phonetic component in “硫” (liu2), “琉”(liu2), “流”(liu2), “梳”(shu1), “疏”(shu1), and “毓”(yu4) is not consistent.

When studying the learning of European languages, researchers found that, if the GPCs are consistent in the target languages, then it will be relatively easier for children to learn new words by taking advantage of the perceived GPCs, even though the GPCs were not explicitly taught [24]. This is one possible explanation for why it is easier for Finnish children to learn their writing system.

Indeed, research results also indicate that learners, even as young as months-old infants [17, 18], are capable of adopting the statistical learning strategies to find regular connections in the environment [1, 15]. Statistical learning does not refer to the machine learning techniques in computer science. It refers to the fact that people can deduce the regularities based on some repeated observations.

3.2 Recognizing Chinese Characters

The written form of Chinese is considered as an ideographic system. Unlike the European languages, Chinese characters are not formed by the combinations of letters in an alphabet, although some researchers attempted to find such a symbolic alphabet for Chinese [7, 12, 13]. The recognition of Chinese characters was once thought to be a task of directly mapping the Chinese characters, which are considered as graphs, to their meanings.

However, there is accumulating evidence that indicates that readers of Chinese texts employ not only the graphical information but also the phonetic and sub-lexical information of the characters in the reading process. Researchers found that reading capabilities of children in China [19], Hong Kong [3, 20], and Taiwan [4, 11] are related to their phonological awareness. A recent study on Spanish, English, and Chinese also suggests the importance of phonological awareness in reading Chinese [2].

Findings observed in brain studies also support the crucial roles of phonological awareness in reading Chinese. Subjects’ performance in the naming task was influenced by whether or not the phonetic components in Chinese characters are consistent [10]. Using functional magnetic resonance imaging (typically referred by fMRI) to monitor subjects’ brain activities, researchers observed similar patterns when subjects read Chinese and alphabetic writing systems [9]. It is also found that, when we monitor subjects’ eye movements with eye trackers, the appearance of phonetic components within the parafoveal area can influence the process of reading Chinese [21].

4. ERRORS IN WRITTEN CHINESE

In this section, we provide evidence that shows the influence of the internal structures of Chinese characters [12, 13, 14], which include the phonetic components, on the errors that we observed in written texts that were produced by students and reported in educational books. The studied errors were confined to those reported errors that were related to the 5401 most commonly used characters that are contained in the first page (0xa440 to 0xc67e) of the BIG-5 Chinese encoding[3].

---

[3] BIG-5 Chinese encoding: http://en.wikipedia.org/wiki/Big5, (last visited on 2 Nov., 2010)

4.1 Types of Errors

We collected 3551 errors in written traditional Chinese and 621 errors in simplified Chinese. The sources include students' compositions in the classrooms, where the students were in the seventh and eighth grades, and educational books in which common errors are discussed. In all of these cases, we have the correct words and the corresponding incorrect words.

We asked two female native speakers, who had no professional training in linguistics, to compare the correct and incorrect word pairs, and classified whether the errors were results of phonetic or visual similarities. Two words are phonetically similar if their pronunciations are similar, and are visually similar if their written forms look similar. For instance, "然候"(ran2 hou4) is an incorrect way to write "然後" (ran2 hou4), and, in this case, the error was most likely due to the same pronunciation of the correct character, "候", and the incorrect character, "後". "旋途" (xuan2, tu2) is an incorrect way to write "旅途" (lu3 tu2), and students might have been confused by the visual similarity between "旋" and "旅". Quite frequently, the incorrect and the correct characters are both visually and phonetically similar, e.g., "獨鐘" (du2 zhong1) is an incorrect way to write "獨鍾" (du2 zhong1).

We compared the annotations returned by the native speakers to achieve Table 1. Given a reported error, when they have consensus, the annotators could classify whether the error was related to phonetic similarity or related to visual similarity. They may consider that both or neither of these factors contributed to the production of the errors. Of course, they were allowed to disagree.

In Table 1, "P" indicates that both annotators believed that the errors were caused by phonetic similarities and "V" by visual similarities. "N" indicates that both annotators believed that errors were not related to either factors, and "B" is for the cases which were related to both phonetic and visual similarities. "D" indicates that the annotators did not agree on their classifications of the errors. The middle row of the table shows that, in traditional Chinese, phonetic similarities participated in the majority, 74.7%, of the errors, and that visual similarities participated in almost half of the errors, i.e., 45.7%. It is remarkable that 28.0% of the errors involved both phonetic and visual similarities. Statistics in the bottom row of the table show the results of the same analysis for 621 reported errors in simplified Chinese. The results also support the importance of the phonetic similarity in the errors. Because the errors that belonged to the "B" category would be counted twice in both the "P" and the "V" categories, we need to add numbers in columns "P", "V", "N" and "D", and subtract the number in column "B" to achieve 100% in the rows (while also considering the rounding errors). For instance, in the middle row, we have 74.7%+45.7%+1.6%+5.9%-28.0%=99.9%.

The statistics in Table 1 show that, when people wrote incorrect words, the errors were more likely to be related to phonetic similarities than to visual similarities.

Table 1. Analysis of observed errors in Chinese texts (notice that : P+V+N+D-B=100%)

	P	V	N	D	B
Traditional	74.7%	45.7%	1.6%	5.9%	28.0%
Simplified	83.1%	48.3%	0.0%	3.7%	35.1%

4.2 Replication of the Errors

In a related study, we attempted to replicate the reported errors that we mentioned in the previous subsection. In each of the reported errors, there is a character that was written incorrectly. Consider a word that contains n characters: $c_1c_2...c_i...c_n$, where $1\leq i \leq n$. Without loss of generality, we can assume that c_i is the wrong character in a reported error. There must also be a way to correct each of the errors, and we assume that the right way to write c_i is to replace it with $\hat{c}_i$. The task of replicating the errors is to test whether our programs can generate the incorrect word $c_1c_2...c_i...c_n$ from the correct word $c_1c_2...\hat{c}_i...c_n$, given our programs "know" that $\hat{c}_i$ is to be replaced by other characters.

Take "獨鍾" (du2 zhong1) for example. It was reported that an incorrect way to write this word is "獨鐘" (du2 zhong1). We could look up a Chinese dictionary to find out all of the characters that can be pronounced in ways that are the same as /zhong1/, e.g., "中" (zhong1), "衷" (zhong1), "煄" (zhong1), and "鐘". We have also designed a special technique to allow our programs to find visually similar characters, e.g., "重"(zhong4), "種"(zhong3 and zhong4), "腫"(zhong3), and "踵" (zhong3) for "鍾".

Hence, to replicate the erroneous way of writing "獨鍾", we replace "鍾" with "中", "衷", "煄", "鐘", "重", "種", "腫", and "踵" to obtain the candidate words "獨中", "獨衷", "獨煄", "獨鐘", "獨重", "獨種", "獨腫", and "獨踵". We then submit these candidate words to a search portal, such as Google, to acquire the estimated number web pages, in traditional Chinese, that contain these candidate words. At the time of this writing, Google's estimates are 304000, 29700, 1, 316000, 277000, 9190, 1730, and 166, respectively, for these candidate words. Hence, based on these estimated counts, our programs consider that the most likely way to write "獨鍾" incorrectly is "獨鐘". If we are allowed to offer the five leading and incorrect ways to write "獨鐘", they would be "獨鍾", "獨中", "獨衷", "獨重", and "獨種". No matter whether we suggest one or five candidate words, the list of the candidate words include the reported error, and our programs can be considered to have replicated the error in this case.

We conducted the experiments in different settings with the reported errors in both traditional and simplified Chinese [12, 13, 14]. It was extremely easy to have the candidate words include the reported errors, if the errors were caused by characters of the same pronunciations. A good machine readable dictionary will suffice. We had to rely on observations obtained from psycholinguistic surveys to determine what pronunciations are "similar." For errors that were related to phonetic similarities, nearly 99% of the reported errors in traditional Chinese were included in the candidate words, when we produced the candidate words with all of the characters that have the same or similar pronunciations with the correct character, i.e., $\hat{c}_i$. It was not as easy to replicate those errors that were related to visual similarities, partially because it was not easy to define visual similarity exactly in the first place. In the most recent experiments, the lists of candidate words included only about 90% of such reported errors.

The 99% and 90% inclusion rates for phonetically and visually similar characters are somewhat illusive. We actually recommended, on average, about 100 candidate characters to achieve these high rates. Although we might subjectively believe that using 100 candidates to capture the incorrect characters that were actually produced should be considered good progress, given that there were 5401 characters in the original pool, it would be still time consuming to select useful characters from 100 candidates when we design games.

When we considered only a limited number of candidate characters that have the leading scores, the chances to include the report errors would drop, but not significantly.

For errors that were related to phonetic similarities, we still could include 88% of the erroneous words in traditional Chinese, with ten leading candidate words. For errors that were related to visual similarities, the top 10 candidates included the erroneous words 77% of the time. We achieved 95.5% and 89.3%, respectively, when we considered only five leading candidate characters for errors that were related to phonetic and visual similarities in simplified Chinese. We note that the reported errors, which we could collect for simplified Chinese, exhibited some special features that made the identification of good candidate characters relatively easier than the identification of candidate characters for errors in traditional Chinese.

The statistics provided in the previous paragraph suggest that the errors that were observed in students' writings and in educational books are also common errors that we can observe in the contents of real-world web pages, particularly those that are related to phonetic similarities.[4]

5. THE INTERACTIVE GAMES

Since computer games have become so popular in the recent decade, digital game-based learning [16] has also become an alternative of the educational measures for computer-assisted language learning (CALL). Because our current goal is to help young students who lag behind in learning Chinese characters, we think it would be a good choice to use computer games in after-school activities as the measure to attract students to learn.

Given the findings of our work and relevant research, we are in the belief that a game [6] that helps students learn the correspondence between the sub-lexical components and the pronunciations of Chinese characters will help students learn Chinese characters more effectively.

The current implementation is based on the Adobe Flash[5], and should be able to be accessed from most, if not all, modern computers via the Internet. We describe the design of the games for unwittingly learning the Chinese GPCs in this section.

5.1 System Requirements

In designing the games, we have the following considerations.

1. Since the games will be used in after-school activities, the design must not be too serious to scare away the students.
2. The most important goal in the games is to learn the Chinese GPCs. Hence there must be natural ways to link the graphemes to the corresponding pronunciations.

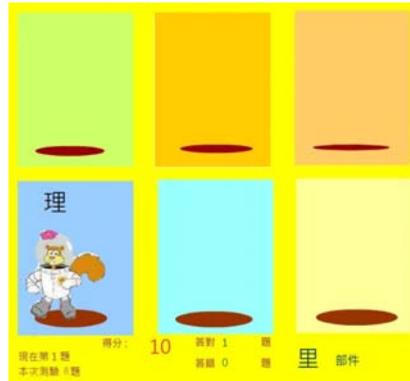

Figure 1. Our game in the Whac-A-Mole style

3. Whenever possible, we would offer feedback in voice to stimulate students both visually and acoustically.
4. There should be mechanisms through which we can control the challenging levels for students of varying competence.
5. If possible, create a mobile version of the games.
6. The system should be able to track the learning statuses of individual students, and allow teachers to statistically analyze the performance of a particular group of students.

5.2 Learners' Interfaces

Users of the games will have to log into the system with a unique identification so that we can store and track their progress statuses. This is also crucial for any personalized services.

To make the game more attractive, we are using a popular game, Whac-A-Mole (WAM, henceforth), with the moles that are major roles in SpongeBob[6]. Figure 1 shows a screenshot of our game. In a typical WAM game, a mole may pop up from each of the holes randomly, and the player needs to hit the mole to receive credits. In our WAM game, the player needs to pay more attention to whether the Chinese character associated with the mole satisfies the condition specified at the lower right corner of the screen. For the example given in Figure 1, the player must judge whether the Chinese character that goes with the mole, "理"(li3) with Sandy, contains the component "里"(li3).

When the player hits a mole, our system will read the character to the player so that s/he can hear the pronunciation of the hit character. The acoustic feedback offers the link between the grapheme and the related pronunciation. If the player hits a mole mistakenly, a brief explanation will be shown in an explaining window.

Based on students' response records, our system will choose the target components and their characters that will go with the moles. The speed at which the moles appear and hide can be adjusted to manipulate the challenging levels of the game.

[4] The statistics were not reported elsewhere in the literature, and much more complete discussions of the experiments are included in an extended report under review. These results are related to those statistics that we reported in previous work [12,14]. (This footnote was requested by a reviewer.)

[5] http://www.adobe.com/products/flashplayer/ (last visited on 2 Nov., 2010)

[6] SpongeBob (http://spongebob.nick.com/) is the property of Nickelodeon (http://www.nick.com), and is a very popular cartoon in both Taiwan and USA. We have replaced the figures with adorable ones of our creation in the latest implementation. Other measures are being taken to avoid the problem of proprietary rights.

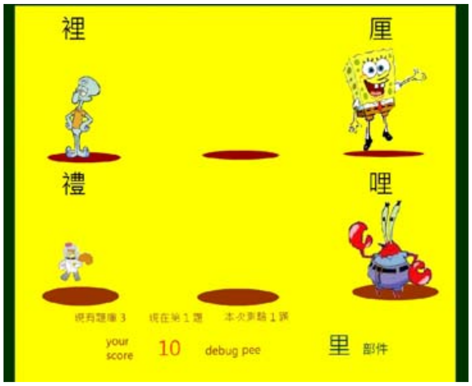

Figure 2. A static version of our game

When the standard WAM game really exceeds the maximum response speeds of the players, an alternative game that shows the moles statically can be chosen. Figure 2 shows a screenshot of this alternative game. In this game, the moles do not pop up dynamically; they will appear and stay still until being hit by the players. Except making the moles static, all of the other aspects of the interactions with the players are the same as the dynamic game.

Although not implemented yet, we plan to have an interface that can adjust to the screen sizes of mobile devices. This should be feasible, at least in a limited sense. To make the WAM minimally challenging, at least two holes should be allowed to show up on the screen at the same time.

5.3 Supporting Technologies

Our system needs a list of characters that carry a particular phonetic component, for all of the phonetic components that the teachers would like the students to learn. Although machine readable Chinese dictionaries might help, the contents of traditional dictionaries are far from satisfactory for our needs.

For instance, it will be easy to find all of the characters that are homophones with the dictionaries. However, homophones at the character level are very common in modern Chinese. There are more than 5000 characters in modern Chinese, but they are pronounced in just 420 different ways [8]. Hence, on average, every 12 characters share a pronunciation. There is no easy way to tell which of those homophones carry the same phonetic component. Moreover, it would be much more difficult to find characters that share an inconsistent phonetic component in any dictionaries, e.g., "流"(liu2) and "毓"(yu4). These two characters share the component "㐬", but do not have the same pronunciation. Moreover, most, if not all, of the radicals in traditional Chinese dictionaries carry semantic information. Hence, "流" and "毓" are not listed under the same radical either.

To alleviate this problem, we have designed a system that helps researchers find visually similar characters for both traditional [13, 14] and simplified [12] Chinese. Our system can return a list of similar characters for a queried character. For instance, given "里", our system for traditional Chinese returns the list "黑俚浬娌埋哩裡鋰墨狸理量童喱嘿野畦重僮潼撞憧鯉鐘". Most characters in this list contains "里", and we need to select those characters that we really need. Although the list is not perfect, such services reduce the search space of more than 5000 Chinese characters to the returned list, therefore greatly improving the efficiency of system implementation. It would be relatively harder for a human expert to write down all of these characters on the fly.

After establishing the database that stores the lists of characters that share the same phonetic components, the next key challenge is to choose the order in which the students should learn about the grapheme-phoneme correspondence. Should we present games for "㐬" before the games for "里" or reversely?

A simple solution is just to follow the current education guidelines set by the Ministry of Education of the government. A more complex solution is to study what might be the best sequence to learn such GPCs with further psycholinguistic studies.

Yet another possibility is, after collecting a sufficiently large amount of students' records, we can build an adaptive system that offers appropriate games that consider students' competence levels and individual interests. In this case, the technologies of student modeling [22] would be in demand.

5.4 More Related Work

The interests in learning Chinese have increased dramatically with the growth of Chinese economy, and there are wide varieties of CALL software for Chinese. Hence, it is not easy to survey all of the software for learning Chinese nowadays. With our limited survey, we are not aware of any running systems that are similar to the one we are proposing in this paper.

The most relevant one that will be reported in a paper, announced a few days before the time of this writing, was authored by Zhou and McBride-Chang [23]. The reported system outlined in the announcement may work on principles that are very similar to ours. The design of their games appears to be different from ours.

In contrast, helping students learn alphabetical languages with phonologic information is not a new idea. For instance, Starfall provides games for learning GPC rules in English[7]. PBS KIDS offers a game for learning rhymes in English[8], but the game for learning Chinese characters in PBS KIDS aims at the composition of the logographs of Chinese characters[9].

6. CONCLUDING REMARKS

Despite that Chinese had been thought to be an ideographic writing system, accumulating evidence suggests that learning Chinese characters shares some common pathways with alphabetical writing systems. Results reported in both neurolinguistic studies indicate that sub-lexical information within Chinese characters participates in the recognition process. Analyses of the errors in Chinese texts further strengthen the importance of phonetic factors in Chinese text processing of the native speakers. It would be interesting to see if further research will show that phonological in-

[7] Learning to read with phonetics, http://www.starfall.com/, in "Learn to Read", (last visited on 2 Nov., 2010)

[8] A PBS-KIDS game for learning rhymes in English, http://pbskids.org/island/preview/gamepreview.html?sesame-supergrover, (last visited on 2 Nov., 2010)

[9] A PBS-KIDS game for learning Chinese characters, http://pbskids.org/sagwa/games/picturesaswords/index.html, (last visited on 2 Nov., 2010)

formation is part of the innate mechanism with which infants take advantage to learn languages [5].

We have built a system that aims at helping students to learn the grapheme-morpheme correspondences in interactive games. The goal is to facilitate students to learn the Chinese characters by extending their knowledge about the sound of characters that the students would have learned at some earlier stages in their learning of Chinese.

Unfortunately, we have a delayed schedule, and have not put our system to work with real students. The arrangements with the host elementary schools require more effort than we had expected, and we are still planning for the detailed design of the evaluation procedure. Hence, we could not provide statistics about how effective our system would accomplish in helping students to learn. We anticipate that this missing element will be patched by the time the paper is presented at the conference.

ACKNOWLEDGMENTS

This research project was supported in part by the National Science Council, Taiwan, under the contracts NSC-97-2221-E-004-007-MY2 and NSC-99-2221-E-004-007. The authors would like to thank the anonymous reviewers for the careful review and helpful comments for the manuscript.

REFERENCES

1. Friedrich, M., and Friederici, A. D. Phonotactic knowledge and lexical-semantic processing in one-year-olds: Brain responses to words and nonsense words in picture contexts. *Journal of Cognitive Neuroscience, 17,* 11, 1785–1802, 2005.
2. Goswami, U., Wang, H.-L. S., Cruz, A., Fosker, T., Mead, N., and Huss, M. Language-universal sensory deficits in developmental dyslexia: English, Spanish, and Chinese. *Journal of Cognitive Neuroscience, 23*, 2, 325–337, 2011.
3. Ho, C. S.-H., and Bryant, P. Phonological skills are important in learning to read Chinese. *Developmental Psychology, 33*, 6, 946–951, 1997.
4. Huang, H. S., and Hanley, J. R. A longitudinal study of phonological awareness, visual skills, and Chinese reading acquisition among first-graders in Taiwan. *International Journal of Behavioral Development, 20*, 2, 249–268, 1997.
5. Jackendoff, R. *Patterns in the Mind: Language and Human Nature*. Basic Books, Jackson, TN, 1994.
6. Johnson, W. L., Vilhjálmsson, H. H., and Marsella, S. Serious use of a serious game for language learning. In *Proc. of the 12th Int'l Conf. on Artif. Intell. in Edu. (AIED '05)*, 306–313, 2005.
7. Juang D., Wang, J.-H., Lai, C.-Y., Hsieh, C.-C., Chien, L.-F., and Ho, J.-M. Resolving the unencoded character problem for Chinese digital libraries. In *Proc. of the 5th ACM/IEEE Joint Conf. on Digital Libraries (ICDL'05)*, 311–319, 2005.
8. Lee, C.-Y. The cognitive and neural basis for learning to reading Chinese. *Journal of Basic Education, 18*, 2, 63–85, 2009.
9. Lee, C.-Y., Huang, H.-W., Kuo, W.-J., Tsai, J.-L., and Tzeng, J.-L. O. Cognitive and neural basis of the consistency and lexicality effects in reading Chinese. *Journal of Neurolinguistics, 23*, 1, 10–27, 2010.
10. Lee, C.-Y., Tsai, J.-L., Su, E. C.-I., Tzeng, O. J.-L., and Hung, D.-L. Consistency, regularity, and frequency effects in naming Chinese characters. *Language and Linguistics, 6*, 1, 75–107, 2005.
11. Lee, J.-R., and Ko, H. Phonological representation unit in the phonological awareness task among Taiwanese students. *Bulletin of Educational Psychology, 41*, 1, 111–124, 2009.
12. Liu, C.-L., Lai, M.-H., Chuang, Y.-H., and Lee, C.-Y. Visually and phonologically similar characters in incorrect simplified Chinese words. In *Proc. of the 23rd Int'l Conf. on Comput. Ling. (COLING '10)*, posters, 739–747, 2010.
13. Liu, C.-L., Tien, K.-W., Lai, M.-H., Chuang, Y.-H., and Wu, S.-H. Capturing errors in written Chinese words. In *Proc. of the 47th Annual Meeting of the Assoc. for Comput. Ling. (ACL'09)*, short papers, 25–28, 2009.
14. Liu, C.-L., Tien, K.-W., Lai, M.-H., Chuang, Y.-H., and Wu, S.-H. Phonological and logographic influences on errors in written Chinese words. In *Proc. of the 7th Workshop on Asian Language Resources (ALR7)*, ACL 2009, 84–91, 2009.
15. Lo, M., Hue, C.-W., and Tsai, F.-Z. Chinese readers' knowledge of how Chinese orthography represents phonology. *Chinese Journal of Psychology, 49*, 4, 315–334, 2007.
16. Prensky, M. *Digital Game-Based Learning*. McGraw-Hill, New York, NY, 2000.
17. Saffran, J. R., Aslin, R. N., and Newport, E. L. Statistical learning by 8-month-old infants. *Science, 274*, 5294, 1926–1928, 1996.
18. Saffran, J. R., Johnson, E. K., Aslin, R. N., and Newport, E.L. Statistical learning of tone sequences by human infants and adults. *Cognition, 70*, 1, 27–52, 1999.
19. Siok, W.T., and Fletcher, P. The role of phonological awareness and visual-orthographic skills in Chinese reading acquisition. *Developmental Psychology, 37*, 6, 886–899, 2001.
20. So, D., and Siegel, L. S. Learning to read Chinese: Semantic, syntactic, phonological and working memory skills in normally achieving and poor Chinese readers. *Reading and Writing, 9*, 1–21, 1997.
21. Tsai, J.-L., Lee, C.-Y., Tzeng, O. J-.L., Hung, D.-L., and Yen, N.-S., Use of phonological codes for Chinese characters: Evidence from processing of parafoveal preview when reading sentences. *Brain and Language, 91*, 2, 235–244, 2004.
22. Woolf, B. P. *Building Intelligent Interactive Tutors*. Morgan Kaufmann, Burlington, MA, 2008.
23. Zhou, Y., and McBride-Chang, C. A. An article announced at http://www.cuhk.edu.hk/cpr/pressrelease/101028e.htm to appear in *Early Education and Development*, 2011. (last visited on 2 Nov., 2010)
24. Ziegler, J. C., and Goswami, U. Reading acquisition, developmental dyslexia, and skilled reading across languages: A psycholinguistic grain size theory. *Psychological Bulletin, 131*, 1, 3–29, 2005.